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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides a method of evaluating effects of shock and penetration on armor weldments, due to projectile impact. Includes procedures for ballistic shock tests of H and double I plate welds, aluminum corner joints, repair welds, and explosion-bulge tests for strain limits of plates and weldments at various temperatures.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RP-702-101
*Test Operations Procedure 2-2-711 — 2 November 1983
AD No.

BALLISTIC TESTING OF ARMOR WELDMENTS

1. SCOPE. This TOP describes ballistic tests to evaluate armor weldments for resistance to shock and penetration by attacking projectiles. These tests are designed specifically for development testing (see MIL-W-46086A[1**]); for acceptance testing, Acceptance Test Procedure No. AP-11/W-1 should be referred to for double-I plates and No. AP-H/W-1 for H-plates.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

ITEM	REQUIREMENTS
Firing ranges	Various, to 90 m (100 yd) long, both open and enclosed
Still camera/film	Standard
Projectiles: plate-proofing, HE and AP appropriate weapons	As indicated in test directive or specification

*This TOP supersedes TOP 2-2-711 dated 1 November 1978.

**Footnote numbers correspond to reference numbers in Appendix D.

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ITEM (cont)	REQUIREMENTS (cont)
High temperature chamber	Maximum temperature 50° C (120° F)
Cooling chamber, liquid CO_2 or mechanical	Capability of cooling to -60° C (-75° F)
Radiographic equipment	For radiographing weldment
Steel butts for holding plates	Capable of holding plate securely at desired obliquity
Explosion-bulge test equipment	As described in para 4.5
Corner joint test facility	As described in para 4.6

2.2 Instrumentation.

ITEM	MAXIMUM PERMISSIBLE ERROR OF MEASUREMENT*
Velocity-measuring instrumentation (TOP 4-2-805[2])	Velocity to 1,200 m/s (4,000 fps) ±0.1%
Temperature-measuring equipment	±1° C (±2° F)
Deep throat micrometer	0.05 mm (±0.002 in.)

3. REQUIRED TEST CONDITIONS.

3.1 Test Criteria. In planning the test, review Appendices B and C to become familiar with the characteristics of armor weld and weldments, criteria for assessing tests results, and terminology used in reporting.

3.2 Radiography. Radiograph all welds to be tested. If any area of a weldment fails to meet radiographic standards (see MIL-R-12643[3]), return the weldment without testing unless authority is received to test plates regardless of radiographic unsoundness.

3.3 Thickness Measurements. Take at least two thickness measurements of each test plate. Check to see if the measured thickness conforms with the requirements of the specification.

3.4 Projectile. Determine the appropriate projectile and its desired striking velocity according to the test directive or specification. Unless otherwise specified, use projectiles as noted in Table 1.

*Values can be assumed to represent ±2 standard deviations; thus, the stated tolerances should not be exceeded in more than 1 measurement of 20.

3.5 Velocity Measurements. Set up equipment for measuring striking velocity (all tests except the explosion-bulge test), using velocity coils for all projectiles except aluminum proof projectiles which require sky screens (see TOP 4-2-805).

3.6 Instrumentation. Install thermocouples when applicable as described in paragraph 4.3.

3.7 Data Required. Record test item identification, temperature if applicable, and other preliminary information indicated on the data collection sheets in Appendix A. Record the measured plate thickness.

3.8 Test Controls.

3.8.1 Warming Gun. Since a "no test" can result if the impact does not strike at the correct velocity or location, it is essential that a new "warmer" round be fired before impacting the plate to establish predictable velocities and alignment.

a. Sight in gun on chipboard target placed in plate butts. (When HE rounds are used, the chipboard must be light enough so as not to detonate the round.)

b. Fire a round with the propellant charge that is expected to give desired striking velocity.

c. Sight and fire a second round even if velocity of first was as expected.

d. Continue until two consecutive rounds have the required velocity, and both impact the aiming point.

e. Replace the "chipboard" target with the test plate (see para 4.1.1).

3.8.2 Temperature Conditioning. Cool plates to be tested at low temperatures to below the prescribed test temperature to allow for temperature rises during the time required for emplacement for firing or detonation (para 4.3.1 and 4.5.1). Test plates conditioned at high temperatures (para 4.5) within 5 minutes after removal from the conditioning chamber.

4. TEST PROCEDURES.

4.1 "H" Plates.

4.1.1 Method.

a. Emplace the plate (see Appendix B) to be tested in a butt of 0° obliquity with the leg welds in a vertical position and clearly exposed.

b. Conduct firings on the plate with the appropriate projectile according to the test directive or specification. Unless otherwise specified, use projectiles as noted in Table 1.

TABLE 1 - PROJECTILES USED IN TESTING ARMOR PLATE H- AND DOUBLE-I WELDS

Projectile	Test Plate Thickness in.	mm	Type of Armor	Striking Velocity fps (±25)	m/s (± 7.6)
M1002, 75-mm (steel) Plate-proofing, weight 15.00 lb.	1-1/2	38.1	Rolled steel Cast steel	1200 1050	365.8 320.0
M1002A, 75-mm (aluminum), Plate-proofing, weight 5.20 lb.	1-1/2	38.1	5083 Aluminum	1050	320.0
M1001, 57-mm (steel), Plate-proofing, weight 6.28 lb.	1	25.4	Rolled steel Cast steel	1050 975	320.0 297.2
M54, 37-mm, HE, with Fuse, PD, M56, weight 1.33 lb.	1/2	12.7	Rolled steel	2525	769.6

(1) Fire projectiles (see TOP 2-2-710[4] for photograph) to impact the leg welds only, one round to each leg, aiming for a point halfway between the cross-weld and the edge of the plate.

(a) The initial impact of the plate-proofing projectiles must at least touch the edge of the weld to be counted "fair."

(b) HE projectiles must impact within 4.5 cm (1-3/4 in.) of the center of the weld to be counted fair.

(c) Projectiles must impact at least 15 cm (6 in.) from the top or bottom of the plate to be counted fair; impacts less than 15 cm from the top or bottom that do not cause excessive cracking are also acceptable.

(2) In development testing, impact each leg weld twice (once above and once below the crossbar weld) unless it becomes apparent that the next impact will cause the test plate to break into two or more pieces.

c. Photograph the rear of the test plate. (An example of the results of firing two rounds on the "H" plate is shown in fig. 1.)

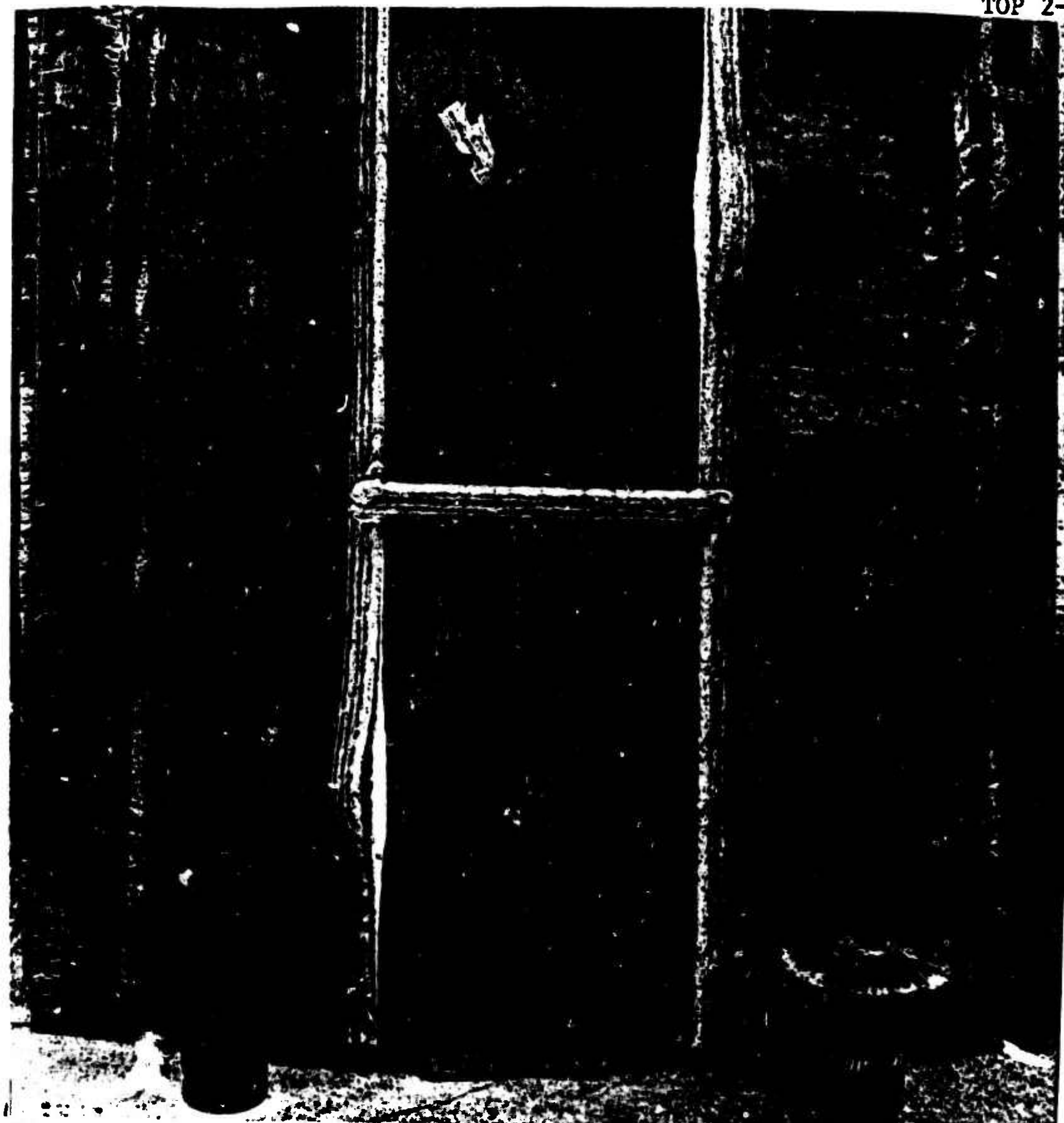

Figure 1. Rear view of steel armor "H" plate after being subjected to shock test with proof projectile.

4.1.2 Data Required. Record the following:

a. Striking velocities
b. Locations of hits
c. Descriptions of cracks as illustrated in Appendix A, Figure A-1, including sketches to depict the cracking on the back of the plate as viewed from the front
d. Properties of armor
e. Supporting photograph

(See also Appendix C for criteria for identifying and appraising cracking.)

4.1.3 Data Reduction and Presentation. Present the data using Appendix A, Figure A-1.

4.2 "Double-I" Plates.

4.2.1 Method.

a. Emplace the plate (see Appendix B) to be tested in a butt at 0° obliquity with the leg welds in a vertical position.

b. Conduct firings on the plate with the appropriate projectiles according to the test directive or specification. Unless otherwise specified, use projectiles as noted in Table 1.

(1) Fire to impact the leg welds, using the fair hit criteria in paragraph 4.1.1b(1). Aim for a point one-third of the way along the weld.

(2) Fire alternating impacts from leg to leg (avoiding overlapping damage) until each leg develops excessive cracks or unless it becomes apparent that another impact will cause the test plate to break into two or more pieces.

c. Photograph the test item, paying particular attention to the welded areas.

4.2.2 Data Required. Record data as indicated in Appendix A, Figure A-1, including appropriate sketches, properties of armor, and photograph.

4.2.3 Data Reduction and Presentation. Present the data using Appendix A, Figure A-1.

4.3 Low Temperature Tests - "H" Plates or Other Welded Plates.

4.3.1 Method.

a. Attach two thermocouples to each steel armor plate in the following manner:

(1) Attach one to the rear face of the plate, 20 cm (8 in.) below and 20 cm to the right of the upper left corner of the plate (as viewed from the rear).

(2) Attach the other symmetrically near the diagonally opposite corner of the first thermocouple.

(3) Weld a metal guard near each of the above thermocouples to support the lead wires.

NOTE: The thermocouples can be silver-soldered to the plate surface or fitted into a drilled well, depending on the thickness of the plate being tested.

b. Attach two thermocouples to each aluminum armor plate by drilling to a prescribed depth, tapping the hole to a depth of 0.9 cm (3/8 in.) to receive a No. 8-32 machine screw, and attaching the thermocouples as shown in Figure 2.

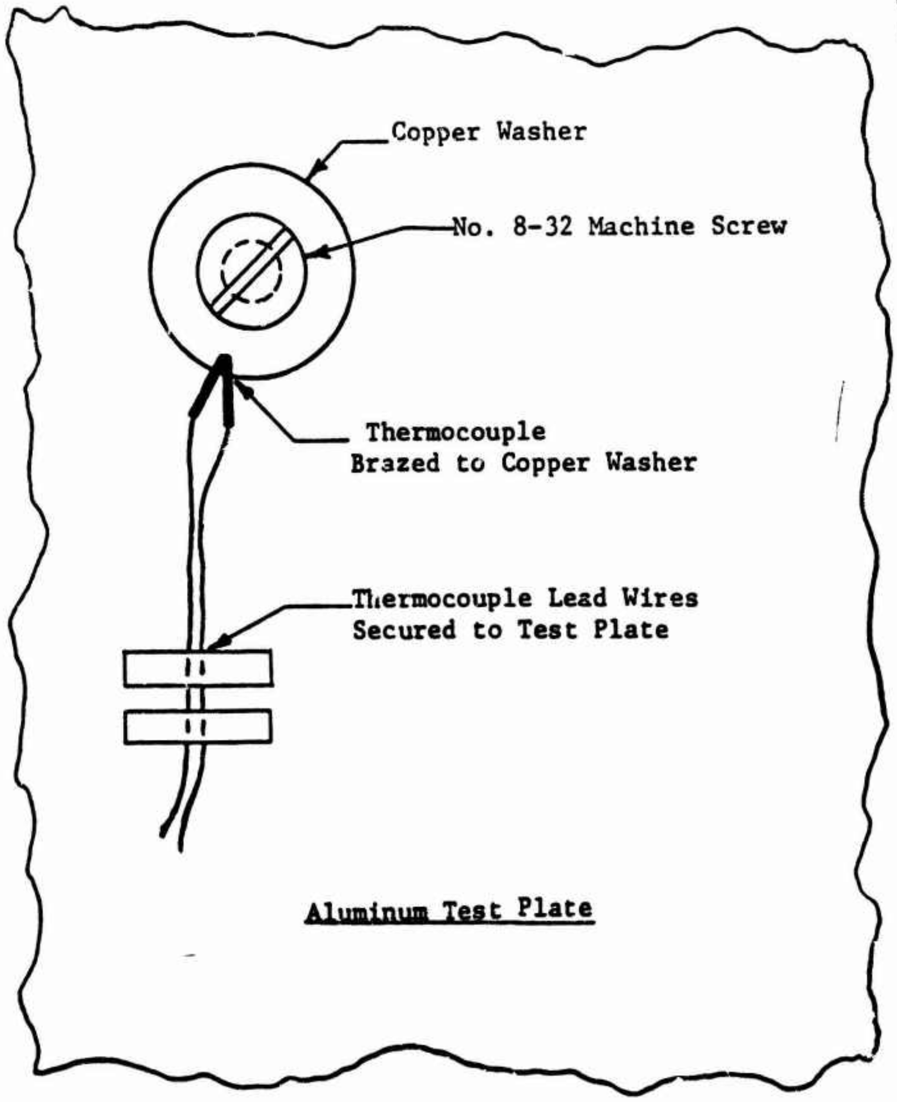

Figure 2. Method of attaching thermocouples to aluminum test plates.

c. Attach thermocouple lead wires to a recorder.

d. Place all of the plates to be tested into a climatic chamber (cooled mechanically or by liquid CO_2) for 16 hours before testing. For each specified test temperature, condition and hold the plates at a temperature below that specified to allow for temperature increases during the time required to mount them in the butts for firing. Table 2 indicates suitable "hold" temperatures.

TABLE 2 - "HOLD" TEMPERATURES

Testing Temperature °F	Testing Temperature °C	Approximate Hold Temperature °F	Approximate Hold Temperature °C
25	-3.9	0 to 15	-18 to -9
0	-17.8	-15 to -25	-26 to -32
-30	-34.4	-40 to -45	-40 to -43
-40	-40.0	-50 to -55	-46 to -48
-50	-45.6	-60 to -65	-51 to -54
-60	-51.1	-70 to -75	-57 to -59

e. When the recorder indicates the proper hold temperature, remove the test plate and mount it in the butt for testing.

f. When the plate reaches the test temperature, conduct firing tests according to paragraph 4.1, except that after each round is fired, replace the test item in the cooling chamber and rechill it (for 1 to 2 hours) to the proper hold temperature before the next round is fired. (It is often possible to fire two rounds quickly before it is necessary to return the plate to the cooling chamber - provided that the plate temperature is within ±2° C (±3° F) of the test temperature. For example, if the prescribed temperature is -34° C (-30° F), the first round can be fired when the plate reaches -36° C (-33° F) and the second before the plate reaches -33° C (-27° F).

4.3.2 Data Required. Record the following:

a. Type and location of thermocouples

b. Temperature at instant of firing

c. Data as indicated in Appendix A, Figure A-1, including sketches, properties of armor, and photograph

4.3.3 Data Reduction and Presentation. Present the data using Figure A-1, Appendix A, or other appropriate form. When appropriate, prepare graphs of length of cracking versus test temperature.

4.4 Area-Defect Plates.[3]

4.4.1 Method.

a. To determine the quality of a weld repair in a plate, subject an area-defect plate (Appendix B, para 3) to the resistance-to-penetration test of TOP 2-2-710. All impacts are to occur totally within the welded area of 0° obliquity.

b. Select the test projectile from Table 3 and fire until an Army two-round ballistic limit is obtained.

NOTE: An Army two-round ballistic limit is the average of two striking velocities, one of which is the lowest velocity that gives a complete penetration according to the so-called "Army" criterion for a complete penetration (see TOP

2-2-710), and the other the highest velocity that gives a partial penetration. The difference between the two velocities must not exceed 15 m/s (50 fps) and the partial penetration velocity must be lower than the complete penetration velocity.

TABLE 3 - PROJECTILES USED IN TESTING REPAIR WELDS ON AREA-DEFECT PLATES

Projectile	Plate Thickness		Type of Armor	Required Ballistic Limit (V50)[a]	
	in.	mm.		fps	m/s
Cal .50, AP, M2	1.0	25.4	Cast steel	2150	655.3
37-mm, AP, M74	2.0	50.8	Cast steel	1450	442.0

[a]Use velocity corrections for thickness in classified supplement to cast armor specification.[5]

4.4.2 Data Required. Record the following:

a. Thickness, type, and properties of armor plate
b. Electrode used in weld
c. Measured thickness of welded area and plate
d. Temperature of plate during firing
e. Type of projectile, striking velocity of each projectile, and whether a complete or partial penetration occurred

4.4.3 Data Reduction and Presentation. Compute Army two-round ballistic limit.

4.5 Explosion-Bulge Test. An explosion-bulge test of a welded plate (see Appendix B) is considered complete when either cracking through the thickness of the weldment is evident or a satisfactory amount of strain has been developed in the base metal. The level of strain considered satisfactory can be at any level from 3% to 15%, depending upon the type of steel used as a base metal and the welding electrode used.

Strain is measured as thickness strain and is defined as the change in thickness (ΔT) divided by the original thickness (T_0) as shown in 4.5.3 below.

Test identical weldments over a range of temperatures. Three indentical detonations are usually required to develop a satisfactory amount of strain in the base metal of each plate. Charge weights, standoff distances, etc. (4.5.1 below), are selected with care to bring about identical explosions at each temperature for each identical weldment.

4.5.1 Method.

a. Measure and record the thickness of the test plate 3.8 cm (1-1/2 in.) from the center of the weld on both sides of the weld. Measure to the nearest 0.025 mm.

b. Set up the saddle plates as shown in Figure 3, and place a lead disk in the bottom of the die to catch fragments in case of severe fracturing of the weldment.

c. Place the weldment on the die, emplace the cardboard box at the prescribed standoff (Table 4), and position the proper pentolite charge on the box. The weight of the charge, the standoff distance, and the size of the die depend upon the type and thickness of the metal as illustrated in Table 4. Table 5 lists the sizes of the standardized pentolite charges.

TABLE 4 - EXAMPLES OF PENTOLITE CHARGE WEIGHTS AND STANDOFF DISTANCES FOR DIFFERENT WELDMENTS

Size of Weldment		Type of Base Metal	Diameter of Die Cavity		Weight of Pentolite		Standoff	
in.	cm		in.	cm	lb.	kg	in.	cm
1 x 24 x 24	2.5 x 61 x 61	Army Armor	16	40.6	7	3.2	18	45.7
1/2 x 20 x 20	1.3 x 51 x 51	Army Armor	12	30.5	3	1.4	24	60.9
3/4 x 20 x 20	1.9 x 51 x 51	STS, NAV-B	12	30.5	4	1.8	15	38.1

TABLE 5 - STANDARD PENTOLITE CHARGES

Weight		Diameter		Thickness	
lb.	kg	in.	cm	in.	cm
3	1.4	8.7	22.1	0.9	2.2
5	2.3	10.0	25.4	1.1	2.9
7	3.2	10.5	26.7	1.4	3.6
9	4.1	14.2	36.1	1.0	2.5

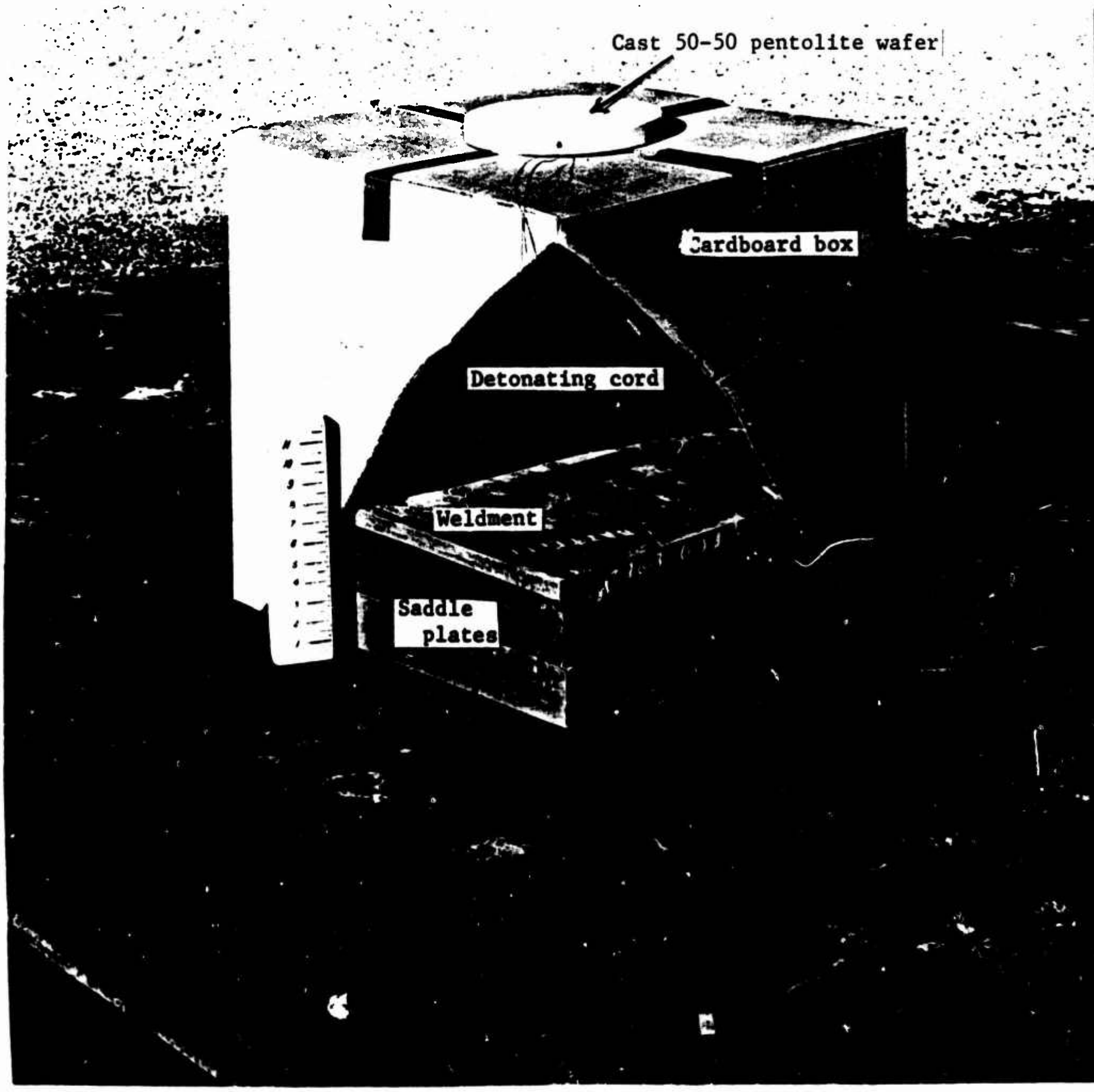

Figure 3. Cutaway view of setup of for explosion-bulge test.

The saddle plates, each 7.6 cm (3 in.) thick, have a circular opening (not visible above) beveled to permit smooth entry of the bulge into the die cavity. The size of the cavity depends upon the size of the weldment (Table 4). The bulge is developed by electrically detonating the pentolite wafer at a specified distance by means of a blasting cap inserted into the center of the wafer from the side. The cardboard box, which supports the charge at the proper standoff, disintegrates during the explosion.

d. Test each plate conditioned at each of the following temperatures unless otherwise specified:

°F	°C
-60	-51
-50	-46
-30	-34
+10	-12
+65	+18
+120	+49

(1) Cool the low-temperature test plates 4° to 7° C (7° to 12° F) below the desired testing temperature.

(2) Test the high-temperature plates (those heated to greater than ambient temperature) within 5 minutes after removal from the temperature chamber.

(3) Conduct three blasts on the test plate (reheating or rechilling before each) if the plate does not break up before the third blast.

e. Measure and record the thickness of the tested plate on both sides of the weld in the same way as for the pretest measurement (a above).

f. Photograph the test plate.

4.5.2 Data Required.

a. Record the following for each test temperature:

(1) Plate number, hardness, Charpy value, type of armor, and manufacturer
(2) Standoff distance
(3) Weight and dimensions of pentolite charge and number of charges
(4) Temperature of test plate
(5) Thickness of plate on both sides of the weld, before and after each detonation
(6) Electrode used in weld
(7) Diameter of die
(8) Type and length of cracking (as described in Appendix B)

b. Draw sketches showing the cracking.

4.5.3 Data Reduction and Presentation. Compute the strain sustained by the test item during the test, using the following formula, and prepare a chart showing the temperature-strain relationship for the test item:

$$\text{Strain} = \frac{\Delta T}{T_o}$$

in which: ΔT = Average change in test item thickness

T_o = Test item original thickness

4.6 Welded Structures. Nearly all joints in armored vehicles are corner joints connecting armor of different thicknesses. Armored vehicle structures of simulated sections of armored vehicles are tested for resistance to shock as described below.

4.6.1 Method.

a. Mount the corner joint or structure to be tested in a facility (fig. 4) designed to hold the joint with the same rigidity as in an actual vehicle.

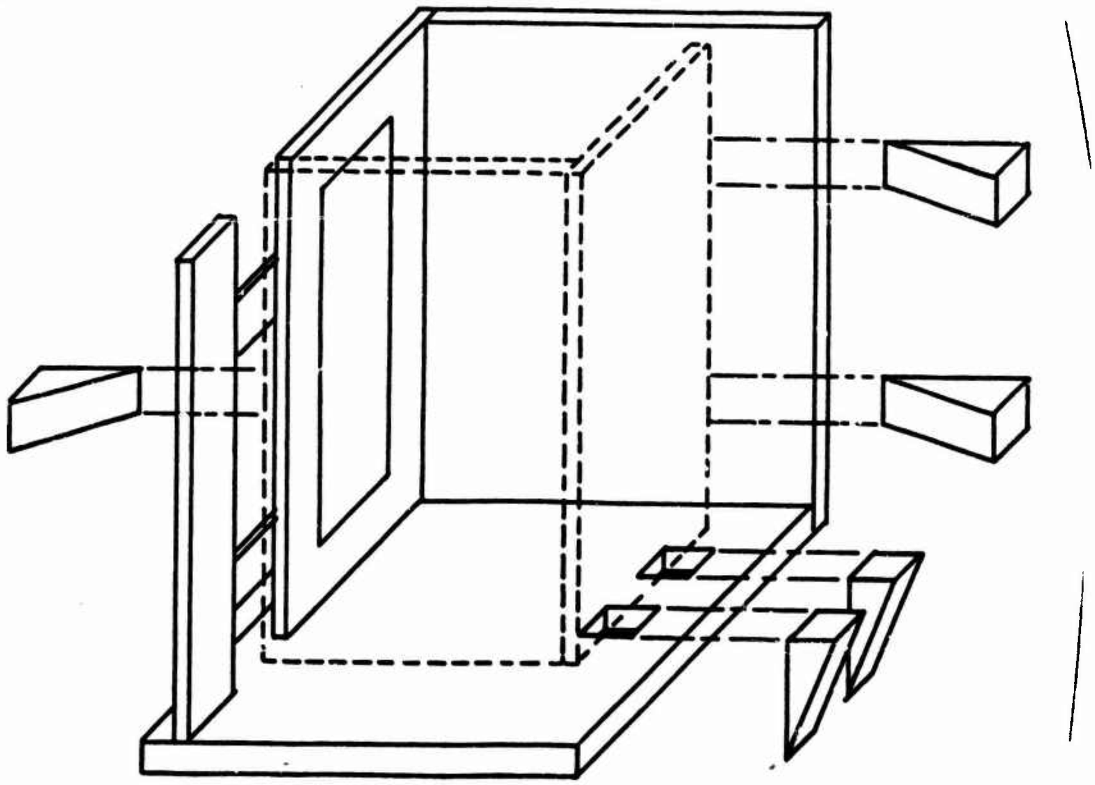

Figure 4. Corner joint testing facility.

b. Conduct firings on the structure with the projectile indicated in the test directive or appropriate specification.

(1) For welded corner joints, fire on one plate at a point close to, but not on, the weld (fig. 5). (NOTE: Depending upon the design of the joint, the attacking projectile could put the weld in compression (most resistant), shear, or tension (least resistant). An explanation is provided in TOP 1-2-613[6].)

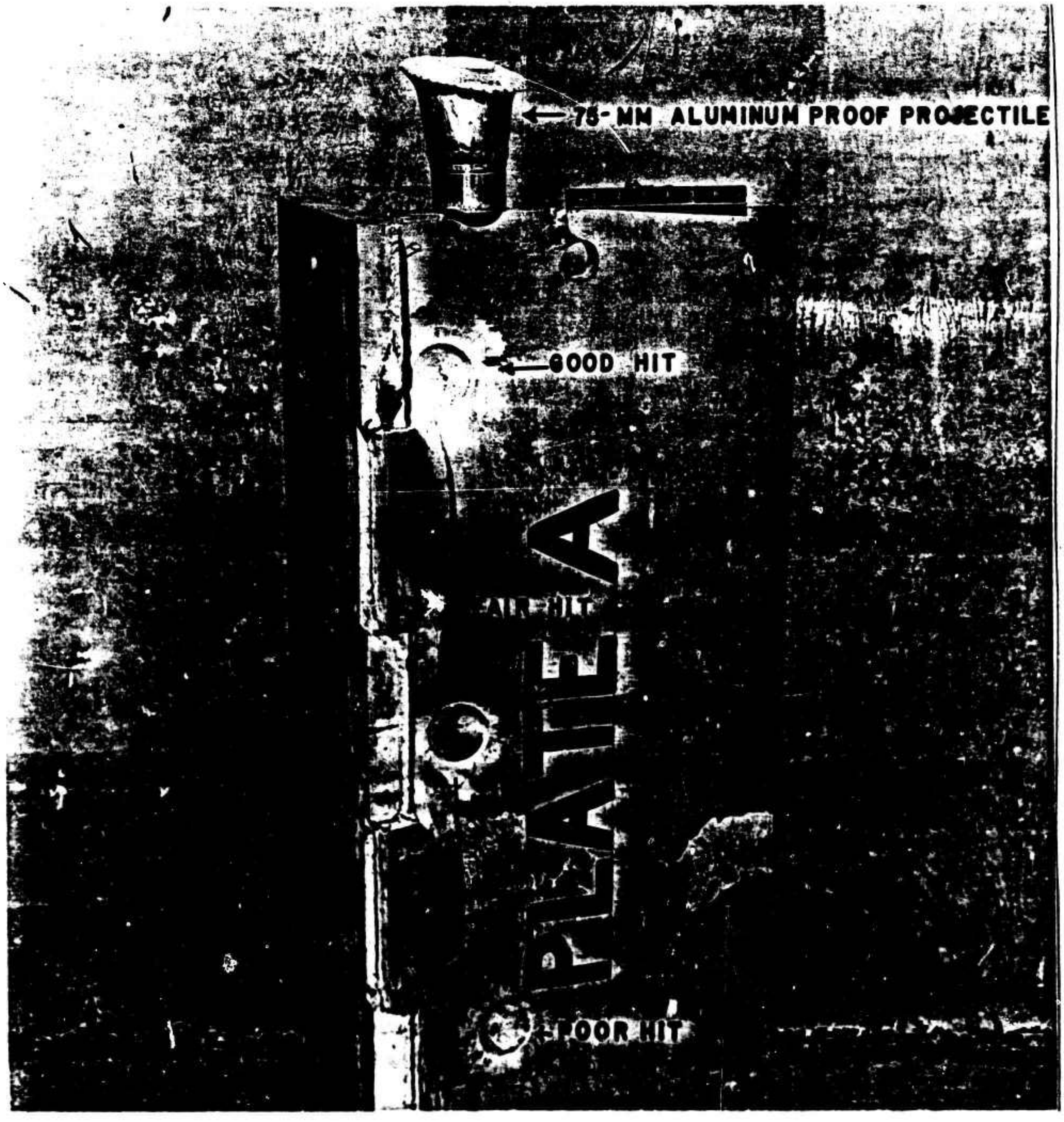

Figure 5. Aluminum corner showing locations of projectile impacts.

(2) For butt joints, fire to directly impact the weld.

(3) Photograph the test item, paying particular attention to the welded areas.

4.6.2 Data Required (see also fig. 7, Appendix A). Record the following:

a. Ambient temperature at time of testing

b. For each round:

(1) Type, thickness, and properties of armor
(2) Measured location of impact
(3) Description and length of weld cracks
(4) Notation of plate cracks
(5) Velocity
(6) Sketches of welded cracks

c. Photograph of impacted test item

4.6.3 Data Reduction and Presentation. Present the data using Appendix A, Figure A-2.

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APPENDIX A

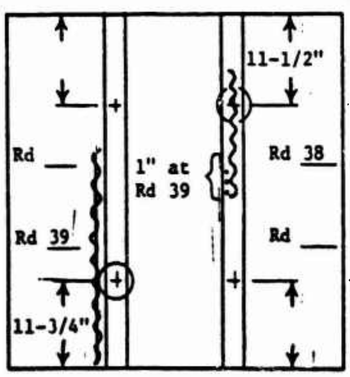
DATA COLLECTION SHEETS

SHOCK TEST OF WELDMENTS

Customer: Plate No.: 1 Thickness: 1-1/8" Type: Al 7039
Type Weld: Joint Design: 2 Projectile: 75-mm, M1002A

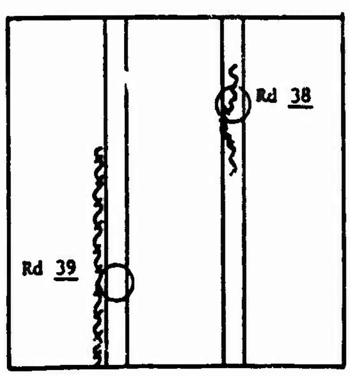
	Rd 38	Rd 39	Rd
Date	5/10/74	5 Oct	
Temp (°F) ~~(°C)~~ (Amb) ~~(Weldment)~~	45	45	
Charge (oz) ~~(g)~~	4.3	4.1	
Velocity (fps) ~~(m/s)~~	1026	1026	

FRONT



Crack Location	Rd 38	Rd 39	Rd
Weld (Bead)	11"	---	
FZ	1" @ Rd 39		
HAZ	---	23"	
Total Weld Area Cracking	11"	23"	
Plate Cracking	---		

BACK



Crack Location	Rd 38	Rd 39	Rd
Weld (Bead)	9-1/2"	---	
FZ	3-1/2"	23-3/4"	
HAZ	---	---	
Total Weld Area Cracking	13"	23-3/4"	
Plate Cracking	---		

Impact ○ Heat Affected Zone Cracking (HAZ)
Weld Cracking Plate Cracking
Fusion Zone Cracking (FZ)

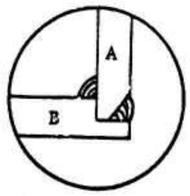
Figure A-1. Sample Report Form - Aluminum double-I weldment. Also used for steel double-I weldments and aluminum and steel H-welds.

SHOCK TEST OF ALUMINUM CORNER JOINTS

Customer:
Type Weld:

Plate No.: 1
Joint Design: 3

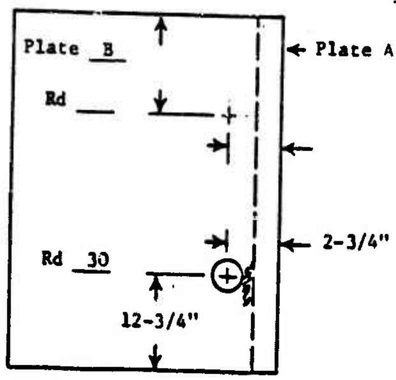
Thickness: 1-1/4" Type Al: 5083
Projectile: 75-mm, M1002A



Corner Joint

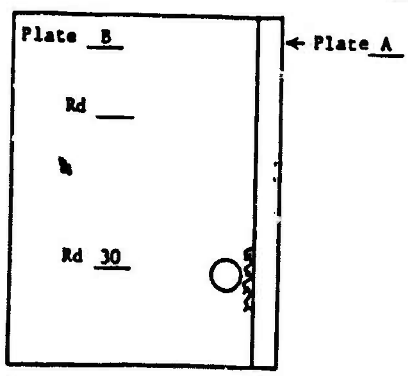
	Rd 30	Rd
Date	9/30/74	
Temp (°F) ~~(°C)~~ ~~(Amb)~~ (Weldment)	72	
Charge (oz) ~~(g)~~	4.45	
Velocity (fps) ~~(m/s)~~	958	

FRONT



Crack Location	Rd 30	Rd
Weld (Bead)	---	
FZ	1-3/4"	
HAZ	---	
Total Weld Area Cracking	1-3/4"	
Plate Cracking	---	

BACK



Crack Location	Rd 30	Rd
Weld (Bead)	---	
FZ	4-3/4"	
HAZ	---	
Total Weld Area Cracking	4-3/4"	
Plate Cracking	---	

Impact ○
Weld Cracking
Fusion Zone Cracking (FZ)
Heat Affected Zone Cracking (HAZ)
Plate Cracking

Figure A-2. Sample report form - aluminum corner joints.

APPENDIX B

TYPES OF WELDED TEST PLATES

1. "H" Plates. Most ballistic test of weldments in H-plates involve shock testing. The plates are 0.9 m (36 in.) square and have a weld in the shape of the letter H as shown in Figure 1. Procedures have been standardized for shock-testing steel armor H-plates in thicknesses of 3, 25, and 38 mm. Since the performance of development H-plates is compared with that of certification H-plates, development H-plates are generally tested with the same projectiles and at the same velocities as specified for ballistic tests for certification (sometimes referred to as qualification tests). Current specifications and Acceptance Test Procedure AP-H/W-1[7] should be consulted before a ballistic test is conducted.

H-welded aluminum armor and structures are tested under relatively the same conditions as welded steel armor plates. They are usually tested with aluminum proof projectiles (or dynamically fired 37-mm or 40-mm high-explosive projectiles). Current specifications (MIL-W-45206A(MR)[8] and other pertinent data should be consulted before a ballistic test is conducted.

2. "Double-I" Plates. Double-I welded plates, as well as area-defect plates, are tested mainly for certifying cast armor repair-welding procedures. (Once certified, a cast armor producer is permitted to repair weld defects in his casting by removing the defect and filling the resultant cavity with weld metal.) Double-I plates are used to determine whether or not the repair procedure will provide a weld with adequate resistance to ballistic shock. The same test conditions used for certification plates are employed for testing development plates so that new welding procedures can be compared with accepted methods. The certification tests of cast steel armor double-I plates are described in the current specifications, which should be consulted before a ballistic test is conducted.

3. Area-Defect Plates. Area-defect plates are submitted for certification of repair-welding procedures to permit repair-welding of defects. The test plate consists of a cast steel armor plate containing a rectangular hole filled with weld metal (fig. B-1).

Area-defect plates are used to determine whether the repair procedures provide a weld with adequate resistance to ballistic penetration. Tests of area-defect plates are the only standardized tests of weldments concerned with resistance to ballistic penetration rather than resistance to ballistic shock. Area-defect plates are 25 or 50.8 mm thick and are tested at 0° obliquity. Current specifications and Acceptance Test Procedure (ATP) AP-A/D-1 should be consulted before a ballistic penetration test is conducted.

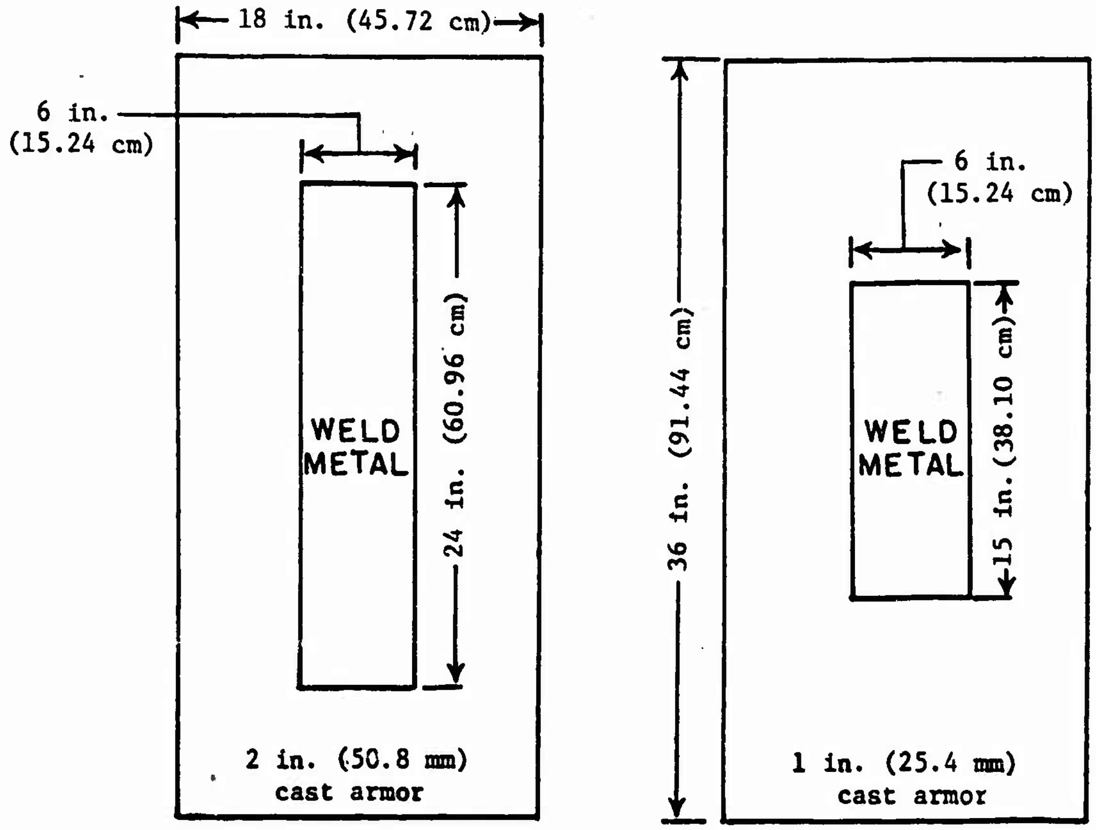


Figure B-1. Standard area-defect plates for testing resistance to penetration of repair welds.

4. Explosion-Bulge. The explosion-bulge test is an auxiliary method for testing prime armor plates as well as weldments. Fundamentally, the test involves bulging a weldment or prime plate into a prepared die by means of an explosive charge. It has an advantage over the H-plate test in that it permits the use of a smaller plate with a simpler weld, and testing conditions can be more closely controlled. The explosion-bulge test can be varied to obtain a wide range of stress conditions. It is useful in determining the transition temperature (that temperature below which failure in test plate changes from the ductile to the brittle type) of various armor materials.

A standard explosion-bulge test weldment consists of a square plate with a butt-weld running through the center. (Other typical weldments suitable for explosion-bulge testing are those with plates having circular patch welds and plates having hard-surfacing weld deposits for base metal crack propagation tests.)

APPENDIX C

CHARACTERISTICS OF ARMAMENT WELDS

1. Evaluation of Ballistic Attack. The proper evaluation of the effects of ballistic attack upon weldments can be made only after the test director has acquired a basic knowledge of the characteristics of welds and a familiarization with welding terms. The outstanding features of one type of welded joint are shown in Figure C-1.

Some terms peculiar to welding are defined below; others are defined in most welding handbooks. The welding terms and definitions used should agree with those shown in Q-STD-324.[9]

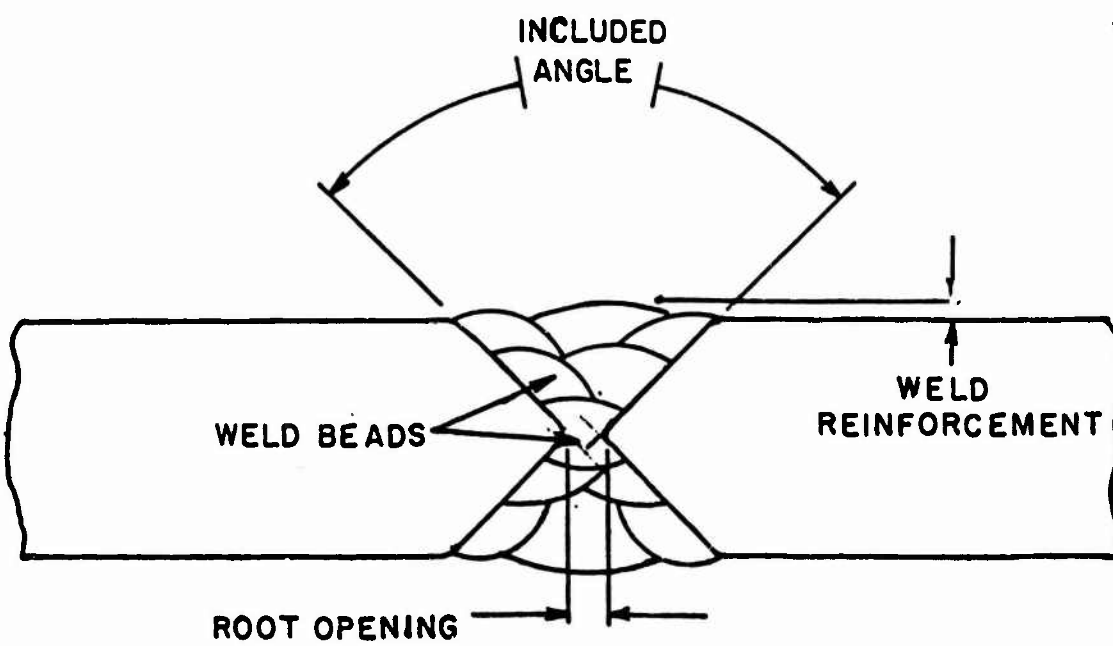


Figure C-1. Salient features of a double-V, full penetration, groove weld.

2. Types of Cracking. In ballistic tests of weldments, not only must the length of the developed cracks be reported, but also the areas in which the cracking occurred must be described. Cracking in weldments resulting from ballistic shock is divided into two general types: weld zone cracking and plate cracking. Weld zone cracking is subdivided into weld metal, plate, and heat-affected zone (fig. C-2).

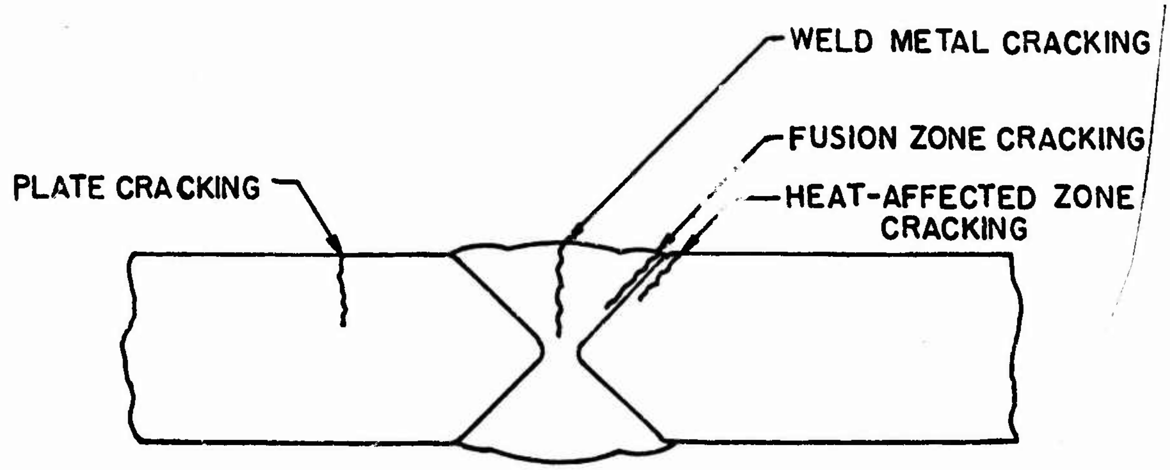


Figure C-2. Types of cracking in welded joints.

For the purpose of reporting ballistic tests, the various areas of a weldment are:

a. Weld zone - That portion of a welded joint which contains the unalloyed metal deposited by the electrode.

b. Fusion line - That portion of the welded joint between the weld metal and unmelted base metal where the weld metal and the base metal have fused.

c. Heat-affected zone - That portion of the base metal which has not been melted, but whose microstructure or mechanical properties have been altered by the heat of welding. (For convenience and consistency, welding specifications specify cracking in the heat-affected zone to be that "cracking in the armor parallel to the weld and within 0.3 cm (1/8 in.) of the edge of the weld." This "0.3-cm" rule is usually acceptable for development tests. High heat input, however, often results in a heat-affected zone that extends beyond 0.3 cm from the weld and may extend 1.6 cm (5/8 in.) in steel or even more in aluminum.)

d. Plate (or base metal) - That portion of the base metal which has not been affected by the heat of welding. (Except as noted above, any cracking that develops farther than 0.3 cm from the weld is usually considered as plate cracking.)

3. Identification of Cracking. It is not always easy to appraise and describe the cracking developed in weldment as a result of ballistic shock. Following are three problems that frequently arise and their solutions:

a. Problem I - To determine exactly in which zone cracking has developed.

Solution I - The test director should examine the crack carefully. With the aid of the definitions in paragraph 2 and Figure C-2, he should be able to make a reasonable appraisal of the location of the cracking. Positive identification of a crack can often be made only by microscopic examination; such examinations are usually made by the manufacturer when the plates are returned.

b. Problem II - When the cracking passes completely through the weld (from front to back), the crack usually originates in one zone at the back of the plate and may revert to another zone. The question then arises as to whether the type of cracking reported should be that which is visible on the surface of the weldment or that which exists inside the joint.

Solution II - If the crack has not opened sufficiently to permit examination of the interior, the zone in which the cracking appears on the surface is reported as the zone of cracking. When it is possible to see into the crack (usually when the weldment breaks into two or more pieces), the cracking is described in terms of that type of cracking that dominates through half of the depth of the weld from the side that is being reported.

c. Problem III - A barely discernible, silvery gray line often develops on the edge of, or within, a weld as a result of an impact. This line usually runs along the junction of the weld reinforcement and the base metal but may occasionally be in the weld metal itself. It is often difficult to determine whether all or part of this line is an incipient crack.

Solution III - Sometimes a silvery gray line forms as a result of the displacement of cracking of scale, rust, or flux. When such a line develops and close examination reveals no trace of a fissure, it is not considered as cracking. Any cleavage of definite break in the metal, however, should be considered as cracking. Even so, it is often difficult to determine whether cracking actually exists and, when it does exist, where it terminates. When a definite answer is required, magnetic particle or dye penetrant examination should be used (TOP 3-2-807[10]).

APPENDIX D

REFERENCES

1. MIL-W-46086A, Welding of Homogeneous Armor by Metal Arc Process, 31 October 1978, and Amendment 1, 2 December 1980.

2. TOP 4-2-805, Projectile Velocity Measurements, 21 September 1982.

3. MIL-R-1264, Radiographic Inspection: Soundness Requirements for Arc and Gas Welds in Steel, 16 August 1982.

4. TOP 2-2-710, Ballistic Tests of Armor Materials, 6 April 1977.

5. MIL-S-11356E, Steel Armor, Cast, Homogeneous, Combat-Vehicle Type (1/4 to 12 Inches, Inclusive), 5 February 1974, Amendment 2/Supplement 1b, 31 March 1975.

6. TOP 1-2-613, Nuclear Effects Test of Army Materiel (Blast), 9 November 1978.

7. ATP AP-H/W-1, Armor, Rolled and Cast, Welded H-Plates, 22 April 1968.

8. MIL-W-45206A(MR), Welding, Aluminum Alloy Armor, 1 December 1966.

9. Q-STD-324, Welding Terms and Definitions.

10. TOP 3-2-807, Nondestructive Testing of Materials, 11 September 1972, and Change 1, 14 November 1975.

11. AP-11/W-1, Armor, Cast, Welded "Double-I" Plates, 22 April 1968.